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INSULATOR DEPARTMENT

GENERAL ELECTRIC COMPANY

Technical Report No. LK-624-DR
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SUBJECT

INVESTIGATION OF EFFECT
OF
STEEP WAVE FRONT IMPULSES ON SUSPENSION INSULATORS

RESTRICTED TO INSULATOR DEPARTMENT USE ONLY

This report contains

12 Typewritten pages
6 Appendixes
2 Sketches
1 Drawing VRA-712-57

Signed Joseph Kaminski Jr Approved Fred C. Vose

I. INTRODUCTION

Reports of failures of a very serious nature on the systems of three important customers had been received. Investigations of failures occurring on one customer's system were carried on and reported in Technical Report No. 604. The above report in part concluded that, "the most likely cause of failure seems to be steep wave front surges of high amplitude."

The above investigations, as well as others carried out by the high voltage laboratory, appeared to have demonstrated, even though to a limited extent, the prevailing conditions existing on a transmission line at the time of failure. Areas in which close correlation appeared to exist between field and laboratory are:

1) Presence of steep wave front impulses initiating the flashover of strings.

2) Puncture of insulators in strings under steep wave front impulses.

3) Presence of high energy currents causing insulators to blow apart or pull apart under tensile loads.

4) Evidence of shell doughnutting under steep wave front impulses.

5) Evidence of depreciation of dielectric strength under steep wave front impulses.

In view of these apparent similarities an extensive program aimed at greater comprehension of the nature and mechanism producing such failures was undertaken.

II. PROCEDURE

The accumulation of additional data was an essential step toward a better understanding of the problem. Therefore, the initial step in the investigation includes a program of comparative testing.

The following insulators from Insulator Dept., Ohio Brass, and Lapp were used:

OB #32440	- 15,000 lbs.	- 5-3/4" spacing
Lapp #8200	- 15,000 lbs.	- 5-3/4" spacing
Locke #1840	- 15,000 lbs.	- 5-3/4" spacing
Locke #18425	- 25,000 lbs.	- 5-3/4" spacing
*Locke #18254	- 25,000 lbs.	- 5" spacing
*Locke #18360	- 36,000 lbs.	- 5-3/4" spacing

All steep wave front tests were made with the impulse generator having an energy input of 7000 watt seconds at 500-KV and an estimated surge current of approximately 7000 amps. ~~The wave shape used was the standard 1-1/2 x 40 microsecond impulse with flashovers occurring on the front of the wave at approximately 350 to 450 KV in 0.5 microseconds.~~ A tensile load of approximately 2000 lbs. was applied continuously to the insulator during the impulse flashover tests. (This above test method was used throughout the entire investigation.)

*Shells made from 304 high strength body.
(18254 previously numbered 18251)

Appendix A represents a compilation of tests on the previously listed insulators. Locke catalog insulators were all made under standard manufacturing practices with standard component hardware. It should be noted that while not reported the influence of insulator spacing, ball bolt style or type of suspension cap had no influence on the outcome of results.

A 60 cycle puncture under oil test was made without prior impulse testing on each group of insulators except OB #32440. This is shown in the report as having received zero impulses. The first two columns indicate the number of impulses and quantity of insulators receiving those number of impulses. The number of units punctured on the specific frequency of impulses is shown as column 3. Tabulated under the Puncture Under Oil heading is the individual values obtained in subsequent puncture under oil tests. The average is determined by totalling the puncture under oil values and dividing by the total number of units tested. For instance, if a unit punctured under impulse, its puncture under oil value would be zero. A measure of the quality of performance is shown in the final column listing the percent failing below 110 KV.

A review of the data with its accompanying summary establishes quite clearly the inferiority of Locke units to those of its competitors. In addition, the extremely poor performance demonstrated by the 18254 units would tend to reflect rather poorly on the 304 body. However, the 18360, made from the 304 body, rather closely parallels the performance of 18425 (both having same shell design 77598).

Insulators failing under impulse by breaking or shattering often exhibited the appearance of "doughnutting." "Doughnutting" of insulator shells is often associated with sudden or high impact loads. It was reasonable to assume either the presence of mechanical impact or high electrical impact during the overvoltage conditions. A series of tests were made on shells for the purpose of establishing either the presence of mechanical or electrical impact. These are reported in Appendix B and although no proof of impact was established it is interesting to note in most tests made with either pin or electrode held tight within the pinhole the failure rate is very high. The pattern of high failure for pins held securely is only altered with the addition of distilled water, molten lead, and mercury. The addition of mercury provided the greatest measure of relief from failure.

Next, all factors and materials related to the insulator shell were critically examined. Insulators were then assembled with shells in stages of completion and under different conditions of firing. It was hoped that by the process of elimination some critical feature of the shell could be established. The shells were prepared as follows:

- Group 1 - Fired without glaze and without sand.
- Group 2 - Fired and glazed but without sand on head or in pinhole.
- Group 3 - Fired and glazed with sand on head but not in pinhole.
- Group 4 - Fired and glazed with sand on head and in pinhole except at the bottom of the pinhole.
- Group 5 - Fired with glaze and sand on head: no glaze and sand in pinhole.
- Group 6 - Fired and glazed with no sand on head but sand in pinhole.
- Group 7 - Unglazed shell with sand on head and in pinhole (epoxy) resin used to bond sand to shell.
- Group 8 - Standard shell fired at bottom of Kiln No. 3.

Group 9 - Standard shell fired at top of Kiln No. 3
Group 10 - Standard shell fired in Kiln No. 2.
Group 11 - Standard shell fired in Kiln No. 1.

Appendix C is a tabulation of results for the above classifications. Under each classification the shell date and puncture value in KV, whether puncture occurred at base of cap or through the head, is shown. The pilot group are 60 cycle puncture tests made without the application of impulses. Under column heading KV and included in groups having received impulses, the letter "P" occasionally appears. This indicates the failure of the insulator occurred under the impulse test. Average KV and percent below 110-KV refer to only the units which have received prior impulse tests.

The significance of results achieved in this series of tests can be grasped almost immediately. A review of all the data focuses sharp attention to the effect sand, particularly its presence or absence in the pinhole, has on the impulse strength of the insulator. While removal of sand from the pinhole alleviates failures under steep wave front impulses it presents an impractical solution to the problem. The improvement shown by group 4, no sand in bottom of pinhole, when compared with groups 8, 9, 10, 11, 12 and the performance for the 1840 shown in Appendix A, provided material for further investigation.

In view of the exceedingly poor results obtained on 1840 shell style, 304 body 18254 insulators, it was of paramount importance to determine if the same factors were influencing both bodies. Five 1840-A3 shells (304 body) were taken from the Ceramic Lab. stock and fired. These were then assembled with component hardware and results are shown as Group 13 under Appendix D. Microscopic examination of fired 304 body particles indicated an abnormal amount of iron impurities. The chief source of this iron impurity was the alumina material used in the mix. Chemically pure alumina or alumina with very low iron content was purchased. Shells were made using chemically pure alumina in the body composition. Nothing else was changed and impulse tests on these insulators are shown as group 15 of Appendix D. In addition to the two aforementioned groups, group 14 standard 304 body and group 16 standard 304 body except without sand in the bottom of the pinhole are also shown.

Just as in the case of the 740 body, the presence or absence of sand in the pinhole was a decisive factor influencing the performance of the insulator under steep wave front impulses. Just by eliminating sand from the bottom of the pinhole the level of improvement when compared with 304 body insulators under Appendix A was as follows:

	Ave. KV	% Below 110-KV
Appendix A (18254 old)	49	93
Appendix A (18254 new)	57	100
Appendix D	124	10

The problem although isolated still provided many divergent paths which were not fully explored. Other questions which had to be resolved were:

1) The effect of acco-polymer or sand glaze additives used for adhesion of sand before firing. The possibility that some deleterious residues were forming after firing needed investigation.

2) Porosity of sand itself raised serious doubt since the addition of cement to an insulator provided a means whereby moisture might be absorbed into the sand, thereby providing highly conducting probes much in the manner of a needle point gap.

3) Laboratory examination of many kinds of sand seemingly indicated that certain characteristics might provide better grain structure and therefore each type must be more fully investigated.

Sand glaze and its adhesives covered in 1 above were tested and reported in Appendix E. Specific tests were made on:

Group 17 - Regular 7000 sand glaze in pinhole; sand on head and in pinhole.
Group 18 - Acco-polymer in pinhole; no sand in pinhole; sand on head.
Group 19 - Standard unit with Karo and glycol instead of acco-polymer in sand glaze.
Group 20 - Standard unit with 100% Karo in sand glaze.

Substituting Karo for acco-polymer does not benefit the insulator. Actually group 18 demonstrates that instead of acco-polymer accelerating failures, the absence of sand in the pinhole provides for an improvement in results.

To fully explore the effect of porosity and better grain structure in sand, a multiplicity of sands in the raw state, made from filter-pressed clays and prefired clays were prepared on shells and assembled into insulators and tested. Appendix F gives complete details and accompanying results with respect to these sands.

Several groups after initial testing gave indications of reasonably good results. Additional assemblies were made in the same manner and were subsequently tested and these same types did not come up to expectations. These groups were as follows:

	INITIAL			REPEAT		
	Group No.	Ave.	%	Group No.	Ave.	%
Prefired #3 Sand	24	136	10	44	66	90
Prefired Zircon Sand	31	139	10	42	120	30
Prefired Zircon Feldspar dry mix	32	149	12.5	39	110	40

The sand exhibiting the most favorable qualities from the standpoint of steep wave front impulses was group 37, filter pressed zircon and feldspar combination. Also showing some promise was the prefired 317 clay and feldspar filter pressed body, group 36. Immediately following the impulse tests sufficient insulators were available to conduct M.&E. and Ultimate tests.

Sample No.	Group 37 M.&E. Lbs.	Group 37 Ultimate Lbs.	Group 36 M.&E. Lbs.	Group 36 Ultimate Lbs.
11	15800	24800	14200	16800
12	13150	23500	14300	18750
13	14850	19050	13050	15500
14	15250	16550	14000	14150
15	17500	22900	14300	18400
16	13600	21350	15150	18200
17	17000	19750	15250	18800
18	15200	22650	12800	18700
19	17600	19750	14000	14900
20	15400	18800	13600	17650
Average	15535	20910	14065	18800

Percent Below 15,000 - 40 } Group 37 80 } Group 36
Percent M.&E. Failures - 100 } 100 }

The poor performance of these sands on M.&E. precluded making additional tests.

Attached to Appendix F is a summary by types of sand. The performance shown is very erratic and substantially the same as shown in Appendix A for standard insulators. It is apparent that modifications to type as well as to manufacturing methods has not provided the desirable results. Sand exhibiting favorable characteristics toward impulse show extremely poor performance on M.&E. and Ultimate tests.

During a period when Manufacturing Engineering was experimenting with the automatic ball making machine and subsequently when automatic ball making equipment was in operation tests were made on shells produced under the experimental and final set ups with the following results:

PUNCTURE UNDER OIL AFTER 5 IMPULSES

Experimental Ball Maker-Group 46 Shell Date	KV	Location	Automatic Production Ball Maker-Group 47 Shell Date	KV	Location
02061	142	H	05222	152	B.C.
02061	136	H	05222	144	H
02061	106	H	05222	90	H
02061	144	H	05222	154	H
02061	80	H	05222	92	H
02061	153	H	05222	145	H
02061	88	H	05222	120	H
02061	140	H	05222	124	H
02061	150	H	05211	140	H
02061	82	H	05211	88	H
Average -	122		Average -	125	

Percent Below 110-KV — 40---Group 46 30---Group 47

Automatic ball making does not relieve the situation but it certainly is not adversely effecting the performance of the insulator under steep wave front impulses.

In Appendix B when shells only were subjected to test, improved performance had been exhibited on shells using mercury and molten lead to secure the pinhole. Assuming the large conducting area prevalent in these assemblies was influencing the results on shells, insulators using 740 body and 304 body were assembled after having sprayed the bottoms of the pinhole generously with copper metal spray. These shells were sprayed with sand remaining in and on the bottom of the pinhole and it was believed that a better electrical distribution would result, such that concentration of electrical stress at the bottom pinhole radius would be relieved.

COPPER SPRAY BOTTOM PINHOLE

740 Body - Group 48			304 Body - Group 49		
Shell Date	KV	Location	Shell Date	KV	Location
04011	P		04181	40	H
04011	146	H	04181	74	H
04011	142	H	04181	66	H
04011	155	H	04181	80	H
04011	156	H	04181	P	
04011	162	H	04181	P	
04011	152	H	04181	72	H
04011	150	H	04181	134	H
04011	P		04181	60	H
04011	156	H	04181	86	H
Average -	122		Average -	61	

Percent Below 110-KV - 20---Group 48 90---Group 49

With the addition of copper metal spray to the bottom of the pinhole on the 740 body there appears to be some slight improvement in performance as compared to results in Appendix A. The improvement is not appreciable and the treatment is found ineffectual when results on the 304 body are taken into consideration.

Referring to Appendix C and D, results on assemblies without sand in the bottom of the pinhole provide material for further investigation. Therefore, shells of the 1840 style 740 body were made with the head thickness increased by approximately 1/16 of an inch and an absence of sand from the bottom of the pinhole. In addition to puncture under oil after impulse M.&E. and Ultimate tests were also made on these units.

NO SAND BOTTOM PINHOLE - INCREASED HEAD THICKNESS (Group 50)

Puncture After Impulse			M.&E. and Ultimate (Pounds)		
Shell Date	KV	Location	Sample No.	M.&E.	Ultimate
02211	152	H	1	19600	22900
02211	142	H	2	17500	19000
02211	138	H	3	15800	15800
02211	170	H	4	13700	21100
02211	156	H	5	23850	23850
02211	170	H	6	18950	18950
02211	200	H	7	18250	19350
02211	150	B.C.	8	23000	23750
02211	109	H	9	15600	20800
02211	85	H	10	25700	25700
02211	164	B.C.	11	24550	24550
02211	144	H	12	23300	23500
02211	142	H	13	20250	20250
02211	175	H	14	14200	16300
02211	156	H			
			Average -	19590	21128
02211	180	H			
02211	120	H	Percent Below 15,000 - 14.2		
02211	120	H	Percent Failing M.&E. - 50		
02211	167	H			

Average - 149

Percent Below 110-KV - 10.5

The apparent improvement in puncture-impulse strength with the increased head thickness, no sand on bottom pinhole combination is offset by the relatively poor M.&E. results obtained on this lot of insulators. The high percentage of M.&E. failures preceeding mechanical failures can only be tolerated at the expense of a depreciation in the normal M.&E. and ultimate test level.

To seek some remedial measures for the disappointing M.&E. performance, it was conjectured that shells without sand in the bottom of the pinhole may be developing unusual voltage gradients at the bottom of the sand band and subsequently under the combined mechanical and electrical stress present electrical failures precipitated. It was thought that brushing sarco into the bottom of the pinhole might change the mechanical load distribution within the pinhole area and remove the high stress from the bottom of the pinhole. Assemblies with added head thickness, an absence of sand, and sarco brushed into the bottom of the pinhole, along with standard head thickness shells having no sand in the bottom of the pinhole, were tested and compared.

SHELLS INCREASED HEAD THICKNESS
NO SAND BOTTOM PINHOLE
SARCO BRUSHED BOTTOM PINHOLE

Sample No.	M.&E.	Ultimate
1	11300	11900
2	12400	12400
3	13300	13500
4	14400	14400
5	16000	16600
6	19550	19550
7	17150	17150
8	14150	14150
9	15200	16200
10	12000	12000
Average -	14545	14785

Percent Below 15,000 - 60
Percent Failing M.&E. - 40

SHELLS STANDARD HEAD THICKNESS
NO SAND AT BOTTOM OF PINHOLE

Sample No.	M.&E.	Ultimate
1	14050	15000
2	26850	26850
3	26950	26950
4	14200	19300
5	17550	18650
6	14900	21000
7	16150	22000
8	18200	18700
Average -	18606	21056

Percent Below 15,000 - 38
Percent Failing M.&E. - 75

Next, it was decided to make shells with the sand band on the outside below the plane of the sand band inside the pinhole (see sketch No. 1). Here again was an effort to redistribute stress away from the critical bottom of the pinhole. With the simultaneous application of load on both cap and pin and the absence of sand at the bottom of the pinhole, it seems very likely that an unbalanced load condition would exist. This unbalance is thought to be a tensile stress applied at the juncture of insulator head and sidewalls and created by the application of load from the lip of the cap transmitted through the sand band and applied from the cobb end of the pin to the sand on the pinhole.

LOWERED EXTERNAL SAND BAND

Sample No.	M.&E. (Lbs.)	Ultimate (Lbs.)
1	17900	21000
2	20700	21100
3	18350	18350
4	20800	21100
5	19800	19800
6	14400	24650
7	20650	20650
8	21650	21650
9	20950	20950
10	13800	19150
Average	18900	20840

Percent Below 15,000 - 20
Percent Failing M.&E. - 50

Since 50 percent of the assemblies failed electrically prior to mechanical failure, the previous supposition could not be supported.

The thought, however, persisted that stress distribution remained the stigma to providing good M.&E. performance with the removal of sand from the bottom of the pinhole. The attempt through lubrication or uniform distribution by the addition of sarco and the alteration of the external sand band to balance combined pin and cap loads had both failed to accomplish the intended purpose, just as the attempt to redistribute electrical stress by applying conducting coatings to the bottom of the pinhole had essentially failed to improve puncture-impulse performance.

Next, it was reasoned that the position of the ball bolt at the bottom of the pinhole was very critical. If this were true, then by placing a washer at the bottom of the pinhole approximately equal to the thickness of the removed sand the relationship of cap, pin, and pinhole radius would remain unchanged and subsequently no electrical preceeding mechanical failures should result.

This idea was put to a test by assembling insulators without sand in the bottom of the pinhole and an asphalt treated felt washer, 1/16 inches thick, placed on the bottom of the pinhole before assembling the pin. A second group identical to the first were dipped in wax.

The results achieved were:

SHELLS, NO SAND BOTTOM PINHOLE ASPHALT WASHER BOTTOM PINHOLE			SHELLS, NO SAND BOTTOM PINHOLE ASPHALT WASHER BOTTOM PINHOLE HEADS WAXED		
Sample No.	M.&E. (Pounds)	Ultimate (Pounds)	Sample No.	M.&E. (Pounds)	Ultimate (Pounds)
1	19700	19700	1	19100	19100
2	23150	23150	2	20650	20650
3	21700	21700	3	19500	19500
4	21050	21050	4	21050	21050
5	20250	20250	5	21750	21750
6	21250	21250	6	21800	21800
7	21550	21550	7	19800	19800
8	21300	21300	8	21400	21400
9	21700	21700	9	22050	22050
10	22000	22000	10	21200	21200
Average	- 21365	21365	Average	- 20830	20830
% Below 15,000	0	0		0	0
% M.&E. Failures	0	0		0	0

The addition of the asphalt washer has produced the desired result. Twenty assemblies tested without failure below 15,000 lbs. and without electrical failures preceeding mechanical failures.

Further demonstration of proof by removing sand from the bottom of the pinhole and adding an asphalt washer to maintain M.&E. strength is shown by the following tests made on 304 body shells. Preceeding the M.&E. data is Puncture Under Oil After 5 Impulses for 18255 assemblies using the 304 body with no sand in the pinhole but an ashphalt washer at the bottom of the pinhole.

PUNCTURE UNDER OIL AFTER 5 IMPULSES

KV	Location	KV	Location
156	B.C.	130	H
85	H	160	B.C.
140	B.C.	92	H
156	H	162	B.C.
144	B.C.	85	H

Average - 131

Percent Below 110-KV - 30

18255 Assembly

NO SAND BOTTOM PINHOLE
NO ASPHALT WASHER

Sample No.	M.&E. (Pounds)	Ultimate (Pounds)
1	26650	32100
2	27500	33700
3	29600	29600
4	32100	32100
5	22450	33450
6	28850	28850
7	30100	30100
8	31250	31250
9	26850	26850
10	28250	28250
Average	28360	30625

Percent Below 25,000 lbs. - 10
Percent M.&E. Failures - 30

18255 Assembly

NO SAND BOTTOM PINHOLE
ASPHALT WASHER ADDED

Sample No.	M.&E. (Pounds	Ultimate (Pounds)
1	30100	30100
2	26100	26100
3	28100	28100
4	27550	27550
5	29850	29850
6	30700	30700
7	27100	27100
8	31850	31850
9	30700	30700
10	34500	34500
Average	29655	29655

Percent Below 25,000 lbs. - 0
Percent M.&E. Failures - 0

III. SUMMARY

Improvement in insulator performance under steep wave front impulses is substantial on insulators having sand removed from the bottom of the pinhole. This is particularly true on 1840 style shells made from the 304 body. For further evidence a resume of all puncture under oil tests after five impulses made during the investigation shows:

	1840 Style 740 Body		1840 Style 304 Body	
	Standard Assemblies	Without sand bottom pinhole	Standard Assemblies	Without sand bottom pinhole
Total tested	60	29	30	20
Average KV	115	142	61	128
% Below 110-KV	35	15	97	20

It is to be noted that while improvement is in positive evidence, complete improvement has not been achieved. Many of the insulators which failed were examined critically; these examinations included porosity, specific gravity, and microscopic examinations. These examinations did not provide any evidence for establishing the pattern of failure. It was of interest to observe that the puncture path in units examined after puncture under oil tests and also in the units failing electrically prior to mechanical failure in the M.&E. test were in the same general area. The attached sketch No. 2 shows the location of these puncture paths. Examination of the sketch shows that the failure originates at the sharp edge of the cobb end of the pin and in the small internal radius at the bottom of the pinhole.

It is reasonable to assume that the small radius between the step of the head and sidewalls provide an area of high electrical field concentration. The same concentration will occur at the edge of the sharp corner of the ball bolt. The placement of pin in the pinhole as required in suspension insulator assemblies makes this area vulnerable to electrical field concentrations.

Similar concentrations of stress will occur through mechanical stress distribution of radii and sharp edges of ball bolts with the application of loads.

The effect of the presence or absence of sand in this area can then only lead to further supposition. It is conjectured that when sand particles of varying shapes and sizes are placed in this zone of high mechanical and electrical stress, the orientation of certain particles with respect to steep wave front impulses follows the behaviour of needle point electrodes promoting even greater electrical stress concentrations which subsequently lead to insulator breakdown.

The application of the above reasoning while explaining the cause of breakdown does not provide an explanation of why 304 body insulators with sand located at the bottom of the pinhole are more susceptible to breakdown under impulse than those of the 740 body. Referring back to Appendix B, it will be recalled that the pattern of breakdown was greatest on shells in which electrodes were held more rigidly in place. It may be possible that the adhesion of sand to the 304 body is somewhat greater than the adhesion of sand to the 740 body and hence the presence of a multiplicity of rigidly held electrodes provides the mechanism for promoting this higher degree of failure.

By removing the sand from the bottom of the pinhole and then subjecting insulators to combined mechanical and electrical tests, a higher percentage of electrical failures occurs. Improvement is immediate if a washer of thickness roughly comparable to the removed sand is placed in the bottom of the pinhole. This undoubtedly reflects on the sensitivity of the critical zone. Moving the pin toward the bottom of the pinhole places both greater mechanical and electrical stress in the vulnerable pinhole radius, and the subsequent application of load results in electrical failure.

Examination of insulators which failed impulse tests but are reported as having sand removed from bottom of pinhole always had clusters of sand particles adhering to a portion of the pinhole radius. More effective sand removal may have led to even greater improvement in performance.

IV. CONCLUSIONS

Immediate improvement in insulator performance under steep wave front impulse surges without detrimental effect when subjected to combined mechanical and electrical loads may be obtained by removing the sand from the bottom of the pinhole and adding a small asphalt washer. It is important to note that the removal of sand from the bottom of the pinhole includes removal of sand from the internal radius. This may be done by instructing glaze wheel operators to avoid brushing acco-polymer below a certain location within the pinhole and adjusting the squirt nozzle to prevent flushing the bottom of the pinhole with glaze. Also, when transporting shells to the kiln, glaze will tend to run down across the internal radius and sand particles shaken loose by vibration will become lodged in the radius. Kiln loaders should be instructed to upset shell and attempt to shake free sand loose. This method will not result in complete freedom from failure but will certainly lead to improved results.

From a long range standpoint much additional work needs to be carried out. For instance, a slight increase in head thickness (Group 50) elevated the individual puncture values in most cases to extremely high values. Lower concentration factors may be obtained by providing a larger radius at the bottom of the pinhole and some further improvement may be gained by increasing the radius of curvature at the top of the head. To further reduce the stress concentrations within the pinhole, it is believed desirable to increase the present radius at the edge of the cobb end of the ball bolt from the present 1/32" to 1/8".

A composite of all these recommended changes is shown on drawing VR-A-712-57.

JKaminski/cp
7/3/57

APPENDIX A

Insulator Designation	No. of Impulses	Qty. Tested	Qty. Punctured	Puncture Under Oil, KV										Ave. KV	Percent Below 110-KV
1840	0	5	-	136	146	150	150	150						146	0
	1	10	-	126	130	134	142	145	146	146	150	150	165	143	0
	2	10	-	92	138	139	150	150	153	154	155	156	160	145	10
	3	20	-	91	107	110	120	120	126	130	136	136	138		
				140	142	143	148	148	150	152	156	156	86	131	15
	4	19	1	80	80	84	112	126	132	134	136	136	140		
				140	140	148	150	150	150	154	156			126	22.2
	5	20	4	76	80	80	80	80	81	88	128	130	132		
				140	146	150	150	156	156					93	55
18425	0	5	-	128	136	150	154	156						145	0
	1	10	-	136	156	156	156	156	156	160	160	170	170	158	0
	2	10	-	83	90	100	105	120	152	155	160	178	180	132	40
	3	10	-	90	112	132	145	146	148	150	154	156	160	139	10
	4	10	-	106	140	142	145	146	146	148	150	152	155	143	10
	5	20	-	80	85	106	110	110	120	132	140	146	150		
				154	154	156	156	156	156	156	156	156	170	137	15

Insulator Designation	No. of Impulses	Qty. Tested	Qty. Punctured	Puncture Under Oil, KV	Ave. KV	Percent Below 110-KV
AB #32440	0	-	-			
	1	-	-			
	2	-	-			
	3	-	-			
	4	-	-			
	5	10	0	80 140 140 144 146 150 152 152 154 156	141	10
Lapp #8200	0	3	0	146 150 150	148	0
	1	-	-			
	2	-	-			
	3	-	-			
	4	-	-			
	5	18	0	146 143 150 150 150 154 154 154 156 156 156 156 156 156 156 156 165 165	154	0
18254 From Old Stock	0	10	0	120 140 140 141 144 146 148 150 156 156	144	0
	1	10	0	80 83 83 90 98 102 109 127 140 148	97	70
	2	10	0	73 76 77 78 80 84 85 120 130 148	95	70
	3	15	0	59 62 64 69 70 70 70 74 78 92 93 120 138 140 146	90	73
	4	14	0	31 43 65 68 70 71 74 78 82 82 84 130 140 146	83	79
	5	15	4	32 36 59 63 63 65 68 72 79 80 117	49	93

Insulator Designation	No. of Impulses	Qty. Tested	Qty. Punctured	Puncture Under Oil, KV										Ave. KV	Percent Below 110-KV
18254 From New Stock	0	5	0	144	144	144	144	148						145	0
	1	10	0	80	82	88	89	110	122	130	132	140	150	123	40
	2	10	0	61	77	77	79	79	81	81	90	112	150	89	80
	3	10	0	78	78	82	90	97	102	142	142	150	153	111	60
	4	10	1	68	78	80	80	80	84	84	86	146		79	90
	5	10	2	60	62	64	70	74	76	78	90			57	100
18360	0	5	0	132	136	150	150	150						143	0
	1	10	1	90	104	106	108	126	134	134	142	142		108	40
	2	10	0	80	80	82	112	130	134	144	150	150	156	122	30
	3	10	0	80	82	84	128	130	130	138	146	148	154	122	30
	4	10	0	84	92	110	120	142	146	150	150	156	170	132	20
	5	10	0	82	85	120	124	140	144	146	150	150	150	129	20

Summary

	1840	18425	OB #32440	Lapp #8200	18254 (old)	18254 (new)	18360
Average Puncture (KV) Under Oil after 5 impulses	93	137	141	154	49	57	129
Percent Below 110-KV after 5 impulses	55	15	10	0	93	100	20

1840 SHELLS (UNLESS OTHERWISE NOTED)

Number of impulses applied to failure (Limit - 20 impulses)

Sample No.	Pin set in molten lead in pinhole	77598 shell with pin set loosely in pinhole (92674 pin)	Pin set in pinhole with mercury added	18400 shell with pin loosely set in pinhole and faschine dye added
1	20	6	20	A 10
2	20	4	20	A 10
3	20	5	20	A 10
4	20	11	20	A 10
5	5	15	20	A 10
6	7	-	20	-

Number of impulses applied to failure (Limit - 20 impulses)

Sample No.	18400 shell pin set loosely in pinhole, zyglo added	77598 shell with 18425-P pin set loosely in pinhole	18400 shell with 73991-1 pin set in pinhole with zyglo added	Pin set in pinhole with zinc metalspray added to pinhole
1	B 10	C 10	D 3	E 10
2	B 10	C 10	D 2	E 4
3	B 8	C 10	D 2	E 4
4	B 2	C 7	D 2	E 6
5	B 2	C 10	D 10	E 5

A - No dye penetration
B - Possibly slight penetration of zyglo
C - No penetration of zyglo
ABCDE - Maximum number of impulses - 10

APPENDIX C

Page 1 of 3

ALL SHELLS 1840 STYLE 740 BODY

	GROUP 1 Plain shell, no sand, no glaze			GROUP 2 Shell glaze, no sand on head or in pinhole			GROUP 3 Shell glazed, sand on head, no sand in pinhole			GROUP 4 Glazed, sand on head, sand in pinhole, no sand in bottom of pinhole		
	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location
Pilot Group	02062	165	B.C.	02052	165	B.C.	02052	168	B.C.	02052	150	H
	02062	152	B.C.	02052	144	B.C.	02052	170	B.C	02052	138	B.C.
	02062	156	H	02051	150	B.C.	02052	146	B.C.	02052	148	B.C.
	02062	160	B.C.	02051	152	B.C.	02052	178	B.C.	02052	152	B.C.
	02062	160	H	02051	148	B.C.	02052	165	B.C.	02052	150	B.C.
Puncture Under Oil after 5 impulses	02062	156	B.C.	02052	142	B.C.	02052	P	B.C.	02082	160	B.C.
	02062	178	H	02052	148	B.C.	02052	168	B.C.	02082	102	B.C.
	02062	160	B.C.	02052	155	B.C.	02052	150	B.C.	02082	140	H
	02062	160	B.C.	02052	156	B.C.	02056	154	B.C.	02082	160	B.C.
	02062	165	H	02052	163	B.C.	02052	165	H	02082	150	
	02062	168	B.C.	02052	155	B.C.	02052	164	B.C.	02082	140	
	02062	160	B.C.	02052	150	B.C.	02052	160	B.C.	02082	45	
	02062	135	H	02052	152	B.C.	02052	165	B.C.	02082	146	
	02062	170	H	02052	160	B.C.	02052	148	B.C.	02082	156	
	02062	165	H	02052	140	B.C.	02052	165	B.C.	02082	150	
Ave. KV		162			152			144			135	
% Below 110-KV		0			0			10			20	

H - Head
B.C. - Base of Cap
P - Puncture under impulse

ALL SHELLS 1840 STYLE 740 BODY

	GROUP 5 Head glazed and sanded, Pinhole unglazed, unsanded			GROUP 6 Glazed, no sand on head, Sand in pinhole			GROUP 7 Unglazed, sand on head and in pinhole			GROUP 8 Standard shell fired Bottom Kiln No. 3		
	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location
Pilot Group	02052	145	B.C.	02052	164	H	02132	114	H	-	-	-
	02052	150	B.C.	02052	146	H	02132	110	H	-	-	-
	02052	142	H	02052	150	H	02132	122	H	-	-	-
	02052	150	B.C.	02052	145	B.C	02132	104	H	-	-	-
	02052	153	B.C.	02052	150	B.C.	-	-	-	-	-	-
Puncture Under Oil after 5 impulses	02052	144	B.C.	02052	P	-	02130	41	H	01201	79	H
	02052	150	B.C.	02052	142	H	02130	P	-	01201	155	H
	02052	160	H	02052	P	-	02130	P	-	01201	144	H
	02052	174	H	02052	152	H	02130	P	-	01201	156	B.C.
	02052	152	H	02052	156	B.C.	02130	P	-	01242	79	H
	02052	142	H	02052	98	H	02130	P	-	01242	150	B.C.
	02052	158	H	02052	95	H	-	-	-	01242	102	H
	02052	140	H	02052	P	-	-	-	-	01242	142	H
	02052	140	B.C.	02052	80	H	-	-	-	01242	142	H
	02052	140	H	02052	P	-	-	-	-	01242	79	H
Ave. KV		150			72			7			123	
% Below 110-KV		0			70			100			40	

H - Head
B.C. - Base of Cap
P - Puncture under impulse

ALL SHELLS 1840 STYLE 740 BODY

	GROUP 9 Standard shell fired Top Kiln No. 3			GROUP 10 Standard shell fired In Kiln No.2			GROUP 11 Standard shell fired In Kiln No. 1			GROUP 12 Standard shell Sponged pinhole		
	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location
Pilot Group	-	-	-	-	-	-	-	-	-	02051	145	-
	-	-	-	-	-	-	-	-	-	02051	148	-
	-	-	-	-	-	-	-	-	-	02051	153	-
	-	-	-	-	-	-	-	-	-	02051	145	-
	-	-	-	-	-	-	-	-	-	02051	152	-
Puncture Under Oil after 5 impulses	01302	130	H	02052	133	H	02041	128	H	02051	78	-
	01292	140	H	02052	68	H	02041	120	H	02051	110	-
	01292	120	H	02052	150	B.C.	01242	86	H	02051	100	-
	01302	124	H	02052	146	B.C.	01312	112	H	02051	140	-
	01302	88	H	02052	140	H	02042	57	H	02051	136	
	01282	150	H	02052	80	H	02052	160	H	02051	P	-
	01301	145	H	02052	122	H	0131	150	H	02051	80	-
	01301	83	H	02052	75	H	02042	146	H	02051	90	-
	01292	152	B.C.	02052	120	H	02041	150	H	02051	60	-
	01292	128	H	02052	123	H	01301	78	H	02051	138	-
Ave. KV		126			116			119			93	
% Below 110-KV		20			30			30			60	

H - Head
B.C. - Base of Cap
P - Puncture under impulse

APPENDIX E

ALL SHELLS 1840 STYLE 740 BODY

	GROUP 17			GROUP 18			GROUP 19			GROUP 20		
	Standard with regular 7000 glaze in pinhole			Acco-polymer in pinhole No sand in pinhole			Standard unit with Karo and Glycol sand glaze			100% Karo and sand glaze		
	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location
Pilot Group	02182	108	H	02192	140	B.C.	02151	152	B.C.	02132	123	H
	02182	116	H	02192	138	B.C.	02151	140	H	02132	128	H
	02182	152	B.C.	02192	156	B.C.	02151	140	H	02132	140	B.C.
	02182	156	B.C.	02192	148	B.C.	02151	141	H	02132	151	B.C.
	02182	144	B.C.	02192	156	B.C.	02152	155	B.C.	02132	146	B.C.
Puncture Under Oil after 5 impulses	02182	105	H	02192	152	B.C.	02151	134	H	02132	80	H
	02182	147	B.C.	02192	80	H	02151	156	B.C.	02132	150	H
	02182	100	H	2192	152	B.C.	02151	90	H	02132	149	H
	02182	156	H	02192	135	H	02151	126	H	02132	P	-
	02182	121	H	02192	143	B.C.	02151	150	B.C.	02132	146	H
	02182	144	B.C.	02192	146	H	02151	146	H	02132	116	H
	02182	75	H	02192	145	B.C.	02151	73	H	02132	45	H
	02182	140	H	02192	109	H	02151	100	H	02132	73	H
	02182	73	H	02192	150	B.C.	02151	P	-	02132	112	H
	02182	P	-	02192	146	B.C.	02151	P	-	02132	78	H
Ave. KV		106			136			97.5			95	
% Below 110-KV		50			20			50			50	

H - Head
B.C. - Base of Cap
P - Puncture under impulse

APPENDIX F

ALL SHELLS 1840 STYLE 740 BODY

	GROUP 21			GROUP 22			GROUP 23			GROUP 24			GROUP 25		
	No. 1 Zircon sand in pinhole			Porcelain sand in pinhole			Alumina Sand No. 2 in pinhole			Prefired #3 sand in pinhole and on head			Prefired 740-1 sand in pinhole		
	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location
Pilot Group	02131	145	H	02182	136	H	02182	136	H	02182	140	H	-	-	-
	02131	150	H	02182	140	H	02182	150	B.C.	02201	153	H	-	-	-
	02131	123	H	02182	121	H	02182	126	H	02201	136	H	-	-	-
	02131	146	H	02182	145	H	02182	142	H	02201	150	B.C.	-	-	-
	02131	143	H	02182	142	B.C.	02182	144	B.C.	02201	144	B.C.	-	-	-
Puncture Under Oil after 5 impulses	02131	149	H	02182	140	H	02182	138	H	02202	150	B.C.	02281	79	H
	02131	116	H	02182	130	H	02182	154	H	02202	152	B.C.	02281	71	H
	02131	140	H	02182	P	-	02182	P	-	02202	154	H	02281	136	H
	02131	80	H	02182	115	H	02182	P	-	02202	86	H	02281	71	H
	02131	150	H	02182	104	H	02182	75	H	02202	145	H	02281	144	H
	02131	71	H	02182	150	H	02182	69	H	02202	152	B.C.	02281	79	H
	02131	156	B.C.	02182	71	H	02182	72	H	02202	122	H	02281	P	-
	02131	165	B.C.	02182	150	B.C.	02182	134	H	02202	126	H	02281	61	H
	02131	80	H	02182	78	H	02182	73	H	02202	129	H	02281	114	H
	02131	150	H	02182	78	H	02182	P	-	02202	146	B.C.	02281	145	B.C.
Ave. KV		125			102			72			136			90	
% Below 110-KV		30			50			70			10			60	

H - Head
B.C. - Base of Cap
P - Puncture under impulse

ALL SHELLS 1840 STYLE 740 BODY

	GROUP 26 Raw No. 317 WG2 sand in pinhole			GROUP 27 Raw Zircon sand			GROUP 28 (18400 Shells) Raw Beryl sand in pinhole			GROUP 29 Raw Zircon and Feld-spar mixed in pinhole			GROUP 30 Prefired 317 sand in pinhole		
	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location
Pilot Group	-	-	-	03021	136	H	03081	136	H	03081	170	B.C.	03051	120	H
	-	-	-	03031	114	H	03081	140	H	03081	146	H	03051	172	H
	-	-	-	02031	132	H	03081	136	H	03081	146	H	03051	138	H
	-	-	-	03031	154	H	03081	116	H	03081	156	B.C.	03051	145	H
	-	-	-	03031	140	H	03081	115	H	03081	148	B.C.	03051	156	H
Puncture Under Oil after 5 impulses	02281	150	H	03031	53	-	03081	82	H	03081	80	H	03051	P	-
	02281	155	B.C.	03031	80	-	03081	P	-	03081	148	H	03051	142	H
	02281	35	H	03031	114	-	03081	P	-	03081	91	H	03051	84	H
	02281	150	H	03031	140	-	02081	P	-	03081	162	B.C.	03051	P	-
	02281	P	-	03031	106	-	03081	P	-	03081	101	H	03051	154	B.C.
	02281	162	B.C.	03031	80	-	03081	122	H	03081	140	H	03051	152	H
	02281	145	H	03031	78	-	03081	72	H	03081	165	H	03051	128	H
	02281	148	H	03031	152	-	03081	77	H	03081	150	H	03051	110	H
	02281	165	H	03031	152	-	03081	74	H	03081	80	H	03051	P	-
	02281	140	H	03031	108	-	03081	40	H	03081	130	H	03051	41	H
Ave. KV		125			100			47			125			81	
% Below 110-KV		20			60			90			40			50	

H - Head
B.C. - Base of Cap
P - Puncture under impulse

APPENDIX F

ALL SHELLS 1840 STYLE 740 BODY

	GROUP 31 Prefired Zircon sand in pinhole			GROUP 32 Prefired Zircon Feld-spar dry mix in pinhole			GROUP 33 Prefired Beryl sand in pinhole			GROUP 34 Beryl prefired filter pressed sand in pinhole			GROUP 35 #3 sand prefired,filt pressed in pinhole		
	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location
Pilot Group		154	B.C.	-	-	-	-	-	-	-	-	-	-	-	-
		154	H	-	-	-	-	-	-	-	-	-	-	-	-
		132	H	-	-	-	-	-	-	-	-	-	-	-	-
		156	B.C.	-	-	-	-	-	-	-	-	-	-	-	-
		145	B.C.	-	-	-	-	-	-	-	-	-	-	-	-
Puncture Under Oil after 5 impulses	03122	150	B.C.	03122	91	H	03122	82	H	04012	82	H	04012	80	H
	03122	152	H	03122	165	B.C.	03122	168	H	04012	78	H	04012	83	H
	03122	140	H	03122	156	H	03122	142	H	04012	138	H	04012	79	H
	03122	170	B.C.	03122	170	H	03122	150	H	04012	80	H	04012	98	H
	03122	144	H	03122	155	H	03122	80	H	04012	P	-	04012	67	H
	03122	90	H	03122	145	H	03122	136	H	04012	P	-	04012	122	H
	03122	130	H	03122	156	B.C.	03122	83	H	04012	101	H	04012	144	B.C.
	03122	140	H	03122	153	B.C.	03122	84	H	04012	165	H	04012	98	H
	03122	132	H	-	-	-	03122	146	H	04012	P	-	04012	50	H
	03122	145	H	-	-	-	03122	165	H	04012	80	H	04012	140	H
Ave. KV		139			149			124			72			96	
% Below 110-KV		10			12.5			40			80.			70	

H - Head
B.C. - Base of Cap
P - Puncture under impulse

ALL SHELLS 1840 STYLE 740 BODY

No Pilot Groups

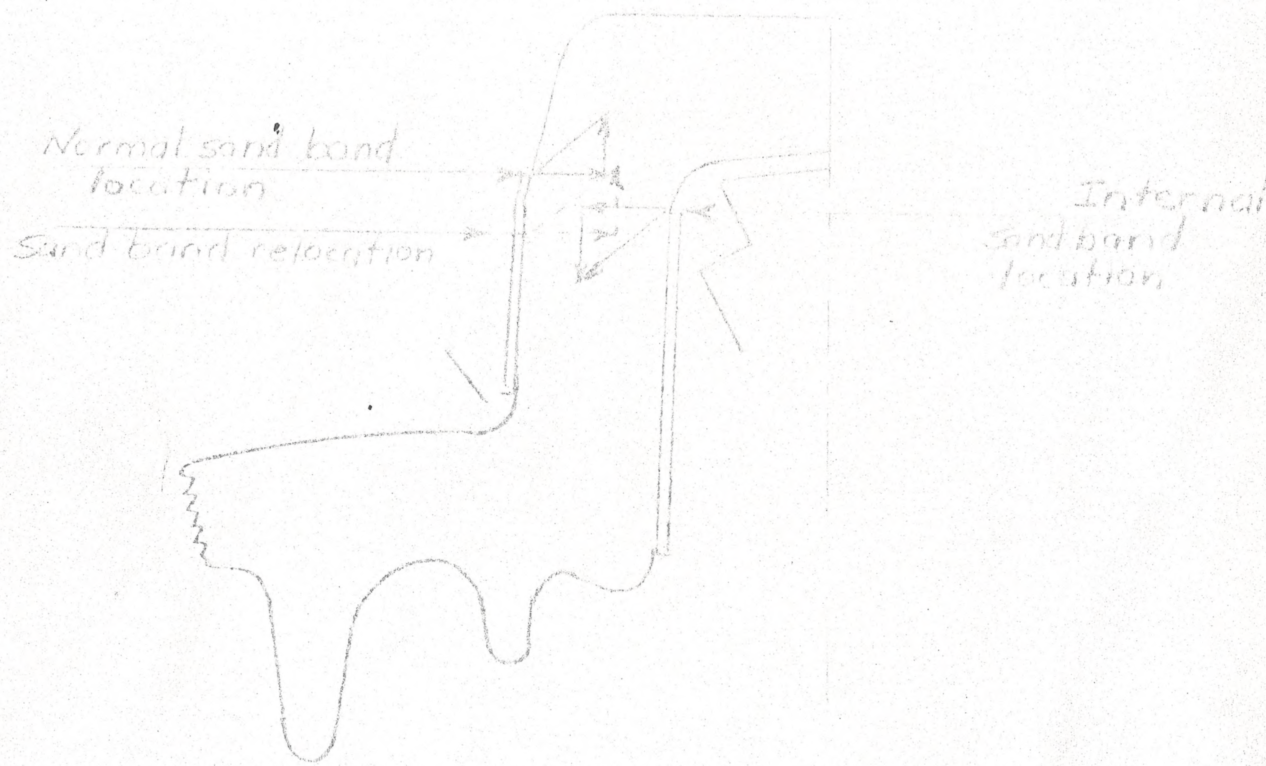
	GROUP 36			GROUP 37			GROUP 38			GROUP 39			GROUP 40		
	317 and Feldspar prefired and filter pressed in pinhole			Zircon and Feldspar filter pressed in pinhole			Prefired 45% Beryl Porcelain in pinhole, dry mix			317 Zircon and Feldspar prefired, dry mix, in pinhole			45% Raw Beryl porcelain in pinhole		
	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location	Shell Date	KV	Location
Puncture Under Oil after 5 impulses	04012	170	B.C.	03281	149	H	03201	156	H	03281	40	H	03281	P	-
	04012	63	H	03281	151	H	03201	80	H	03281	152	H	03281	P	-
	04012	148	H	03281	170	B.C.	C3201	119	H	03281	78	H	03281	135	H
	04012	152	H	03281	156	H	03201	80	H	03281	76	H	03281	78	H
	04012	69	H	03281	165	B.C.	03201	78	H	03281	90	H	03281	140	B.C.
	04012	150	H	03281	144	H	03201	61	H	03281	154	H	C3281	125	H
	04012	170	H	03281	155	H	03201	69	H	03281	130	H	03281	76	H
	04012	150	H	03281	147	B.C.	03201	P	-	03281	126	H	03281	P	-
	04012	132	H	03281	71	H	03201	86	H	03281	P	-	03281	79	H
	04012	122	H	03281	128	H	03201	P	-	03281	150	H	03281	142	H
Ave. KV		133			144			73			110			78	
% Below 110-KV		20			10			80			40			60	

H - Head
B.C. - Base of Cap
P - Puncture under impulse

	Quantity Tested	No. of Failures	Percent	Average KV
		No. 3 Sand		
Prefired	10	1	10%	66
Prefired	10	9	90%	96
Prefired, Filter Pressed	10	7	70%	86
Filter Pressed	10	6	60%	-
		Beryl Compositions		
Raw	10	9	90%	47
Prefired	10	4	40%	124
Prefired, Filter Pressed	10	8	80%	72
45% Beryl Porcelain, Dry Mix	10	8	80%	73
45% Beryl Porcelain, Raw	10	6	60%	78
45% Beryl Porcelain, Raw Dry Mix	10	10	100%	67
		317 Compositions		
Raw WG2	10	2	20%	125
Prefired	10	5	50%	81
317 and Feldspar, Prefired, Filt. Pressed	10	2	20%	133
317 and Feldspar, Filter Pressed	10*	1	10%	144
317 and Feldspar, Prefired, Dry Mix	10	4	40%	110
		Zircon Compositions		
Raw	10	6	60%	100
Raw Zircon and Feldspar	10	4	40%	125
Prefired	10	1	10%	139
Prefired Zircon and Feldspar	8	1	12.5%	149
Prefired	10	3	30%	120
No. 1	10	3	30%	125
Zircon and Feldspar, Filter Pressed	10*	1	10%	144

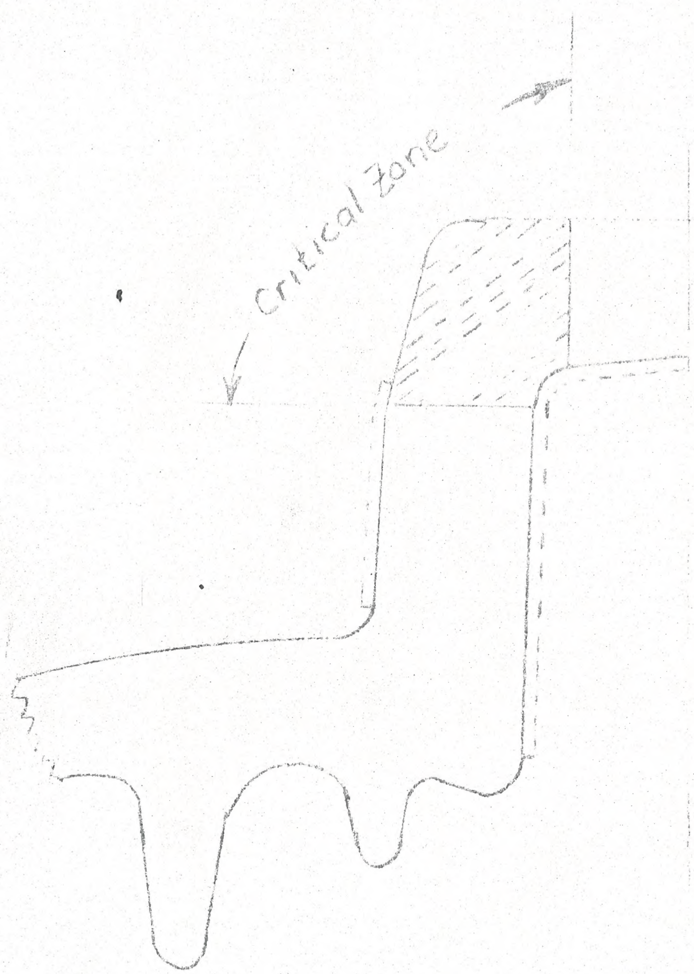
*Same group of insulators

SKETCH
No. I



Normal sand band
location
Sand band relocation
Internal
sand band
location

SKETCH
No 2



Most frequent occurrence of puncture
paths on impulse and M&E failure
occur in critical zone